BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Apollo Lunar Surface Experiments Package Flight Support System Sizing Estimates - Case 900

DATE: August 19, 1968

FROM: R. J. Pauly

ABSTRACT

Sizing estimates have been prepared for an Apollo Lunar Surface Experiments Package real-time flight control computer system. The estimates are presented as an example of a system which could perform the flight support function. Simultaneous support of two ALSEPs was assumed.

The computer system would process approximately 1,000 telemetry parameters and initiate up to 200 commands. The telemetry parameters would be received at a rate of 212 samples per second. They would be decommutated, converted to engineering units, limit checked, and displayed.

The computer system would consist of the following principal features:

1. A central processing unit capable of executing at least 35,000 instructions per second, with a core storage capacity of 90,000 8-bit bytes or 32,000 24 to 36-bit words.

2. Two 600 lines-per-minute printers, a card reader/punch, a number of display lights, and a command console typewriter attached to a computer input/output channel.

3. A magnetic tape unit and 100,000 bytes of disk storage attached to a computer input/output channel.

4. Eight drum recorders and three 8-channel strip chart recorders attached to a computer input/output channel.

5. A communication network interface terminal attached to a computer input/output channel.

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MEMORANDUM FOR FILE

INTRODUCTION

This memorandum presents sizing estimates for an Apollo Lunar Surface Experiments Package (ALSEP) real-time flight control computer system. Estimates of computer instruction execution time, core storage, and peripheral devices are included.

The sizing estimates are based on the ALSEP Flight 1/ Flight 2 configuration support requirements. These are considered to be representative for other flights.

The real time flight control activities will be as follows:

1. Initialization and Calibration - After the astronauts deploy the ALSEP, the experiments will be turned on, initialized and calibrated. Control Center personnel will initiate commands, and monitor the ALSEP's response to the commands. The experiments may have to be recalibrated from time to time throughout the remainder of the mission.

2. Monitoring - Aperiodically throughout the mission the experiments and subsystems will be monitored. Commands will be initiated as required to improve performance.

Up to three ALSEP missions must be supported, with two handled simultaneously. Support will be provided:

1. Continuously during the first 45 days of each mission.

2. For two hours per day during the remainder of each mission.

3. Twice a month for up to 60 hours, at each lunar sunrise and sunset.

PROCESSING REQUIREMENTS

The computer system must handle subsystem data, experiments data and commands. The subsystem and experiments data must be decommutated, converted to engineering units, and

displayed. The subsystem data must also be limit checked. Commands must be initiated and their execution verified.

In the normal operating mode each ALSEP will telemeter one frame of data containing sixty-four 10-bit words each 0.604 second. The 64 words in each frame are allocated as follows:

Function	Words/Frame
Telemetry System Control	3
Passive Seismic Experiment	43
Magnetometer Experiment	7
Suprathermal Ion Detector and Cold Cathode Gauge Experiment	5
Solar Wind Experiment	4
Subsystem Housekeeping	1
Command Verification	1

The experiment, subsystem and command data structures are discussed below:*

1. Passive Seismic Experiment (PSE) - Two ALSEP frames are required to complete a PSE cycle. The cycle consists of 86 words and repeats every 1.2 seconds. Eight, 10-bit scientific parameters are supercommutated in 43 words per frame. The parameters can be grouped in five calibration categories, each requiring a separate calibration curve to convert the parameters to engineering units.**

2. Magnetometer Experiment (ME) - Sixteen ALSEP frames are required to complete an ME cycle. The cycle consists of 112 words and repeats every 9.6 seconds. Three, 10-bit scientific parameters are supercommutated in six words per frame. Eight, 7-bit engineering parameters and nineteen 3-bit engineering parameters are subcommutated in one word per frame. The parameters can be grouped in five calibration categories.

3. Solar Wind Experiment (SWE) - Seven hundred and forty-four ALSEP frames are required to complete an SWE cycle. The cycle consists of 2,976 words--16 sequences of 186 words--and repeats every 446 seconds. One hundred and sixty-eight 8-bit scientific parameters

*See references 1, 2 and 3 for a more detailed description of the ALSEP formats.

**Sensors with the same range and accuracy are grouped in a common calibration category for the purpose of performing engineering unit conversions.

and ninety-two 8-bit engineering parameters are subcommutated in four words per frame. The parameters can be grouped in 12 calibration categories.

4. Suprathermal Ion Detector Experiment/Cold Cathode Gauge Experiment (SIDE/CCGE) - Two hundred and fifty-six ALSEP frames are required to complete a SIDE/CCGE cycle. The cycle consists of 1,280 words--10 sequences of 128 words--and repeats every 154 seconds. Two 20-bit parameters are subcommutated in two words per frame. One hundred and ninety-four 7 or 8-bit parameters are subcommutated in three words per frame. The parameters can be grouped in 30 calibration categories.

5. Subsystem Housekeeping - Ninety ALSEP frames are required to complete a housekeeping cycle. The cycle consists of 90 words and repeats every 54 seconds. Ninety 8-bit parameters are subcommutated in one word per frame. The parameters can be grouped in 46 calibration categories.

6. Command - There are sixty-six 61-bit command words, each containing one command. Each ALSEP frame contains one 10-bit command verification word which indicates the last accepted command.

COMPUTER PROGRAM DESIGN

Functional flow charts for an ALSEP computer program were developed in order to size the flight support computer. A program overview is presented in Figure 1 and the major program functions are presented in more detail in Figures 2-7. The functions are:

1. Initialize program.
2. Initiate commands and request display formats.
3. Manned Space Flight Network (MSFN) data input.
4. MSFN input processing.
5. Decommutate.
6. Calibrate.
7. Limit test.
8. Display.

Worst case estimates of the number of instructions executed per 10-bit ALSEP data word processed, total number of program instructions, data table storage and work area storage were developed. The number of instructions executed per data

word processed multiplied by the ALSEP telemetry input rate will indicate the internal speed requirements of the flight support computer. The number of program instructions, data table storage and work area storage will indicate the internal core memory and auxiliary memory requirements. The estimates are presented in terms of a byte oriented computer. An average instruction size of four 8-bit bytes is assumed.

The estimates represent the author's engineering judgement, based on an evaluation of the functions depicted in the flow charts. The flow charted functions and estimates are described below:

1. Initialize Program (Figure 2) - In this function all variable program conditions are initialized. Since the initializing activity is performed only at the beginning of each support period, it would have a negligible impact on the estimate of total instructions executed per data word processed. Twenty-five instructions requiring 100 bytes would be required to support one ALSEP and 50 instructions requiring 200 bytes would be required to support two ALSEPs.

2. Initiate Commands and Request Display Formats (Figure 3) - This function is performed prior to processing each ALSEP frame. It enables the flight control personnel to initiate commands to the ALSEP and to select formats for displaying the ALSEP telemetry parameters.* Requests are initiated from a flight control console. Two cycles through this function are required to service each request. One cycle is required to recognize the request and initiate an input to the computer. The next cycle is required to process the request. Commands are output to the Manned Space Flight Network (MSFN) and new display formats are retrieved from auxiliary storage.** The actions taken are indicated at the flight control console.

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*An initial selection of display formats is included with the ALSEP program, when it is loaded into the computer.

**When a new display is requested, the display it is replacing will be terminated. The new display will be presented after the new display format is retrieved from auxiliary storage and the parameters to be displayed have been assembled in a display buffer.

Sizing Estimates

A. Instructions executed per data word = less than 1*

B. Instructions - one or two ALSEPs = 55 = 220 bytes

C. Table storage - one ALSEP = 530 bytes

D. Table storage - two ALSEPs = 1,060 bytes

E. Work area - one or two ALSEPs = 25 bytes

3. MSFN Data Input (Figure 4) - It is assumed that the ALSEP data are routed from the remote sites to GSFC in standard MSFN 2400 bit messages at one second intervals. Five frames from each ALSEP are included in every three messages. At GSFC, each message is repacked along with overhead information into five 600 bit data blocks and routed to MSC in the same manner as Apollo data. The data blocks are input to the flight support computer from equipment interfacing with the data circuits from GSFC. An input is initiated when a data present signal is sent from the interface equipment to the computer. The executive routine interrupts the computer activity being performed and reads the ALSEP data into an input buffer. Message synchronization is established when the first block of a three message--five ALSEP frame--sequence is read.

   The inputs occur aperiodically with an average input rate of one telemetry frame per 0.604 second from each ALSEP. The input buffer retains the last three seconds of data received. The three second input buffer allows the other computer processing functions to be performed periodically, on a frame by frame basis.

   Sizing Estimates

   A. Instruction executed per data word = less than 1

   B. Instructions - one or two ALSEPs = 16 = 64 bytes

   C. Work area - one or two ALSEPs = 1,125 bytes

4. MSFN Input Processing (Figure 5) - In this function data in the input buffer are assembled into frames.

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*Since this function is performed prior to processing each ALSEP frame, the number of instructions executed in the function divided by the number of data words in a frame yields the instructions executed per data word (i.e., $\frac{47}{64}$ for one ALSEP and $\frac{47}{128}$ for two ALSEPs).

One frame is assembled each time the function is performed. After the frame is assembled the Greenwich Mean Time (GMT) and the quality indicators (e.g., frame synchronization words, frame count, etc.) associated with the frame are examined. The GMT and quality flags are loaded into display buffers. If ALSEP frame synchronization is lost, a search mode flag will be set for the decommutate function.

Sizing Estimates

A. Instructions executed per data word = 12*

B. Instructions - one ALSEP = 52 = 208 bytes

C. Instructions - two ALSEPs = 104 = 416 bytes

D. Work area - one ALSEP = 130 bytes

E. Work area - two ALSEPs = 260 bytes

5. Decommutate (Figure 6) - This function decommutates the previously assembled frame of ALSEP data. It operates in a search mode and a cycle mode. In the search mode the ALSEP parameters are examined to identify the beginning of each of the experiment cycles and the subsystem housekeeping cycle. Since the various cycles are not synchronous, the function will at times be in the search mode for one experiment and the cycle mode for another.

   When operating in the cycle mode, display format tables are used to select the appropriate calibration routine, test limits, and display buffer location for each parameter which is to be displayed.** One parameter is decommutated each time the function is performed. The display tables indicate the action to be taken on each parameter in each of the various cycles. For example, the housekeeping display table:

   a. Points to a calibration routine and calibration constants for each parameter.

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*The activity depicted in the flow chart box "Assemble Next ALSEP Telemetry Frame" consists of a series of instructions which must be repeated for each data word in the frame. The activities depicted in the other flow chart boxes are performed once per frame.

**Twenty-five formats are provided to allow a variety of experiment and subsystem display combinations. Approximately 100,000 bytes of off-line storage are required for the formats.

b. Points to a display buffer location for each parameter.

c. Contains an upper test limit for each parameter.

d. Contains a lower test limit for each parameter.

Sizing Estimates

A. Instructions executed per data word = 20

B. Instructions - one ALSEP = 160 = 640 bytes

C. Instructions - two ALSEPs = 320 = 1,280 bytes

D. Table storage - one ALSEP = 7,360 bytes

E. Table storage - two ALSEPs = 14,720 bytes

6. Calibrate and Limit Test (Figure 7) - After an individual parameter is decommutated it is calibrated, limit tested if required, converted to the appropriate display code format and stored in the appropriate display buffer location. It is estimated that 16 calibration routines with 102 sets of constants, four calibration/limit test routines with 92 sets of constants and three conversion routines would be adequate to handle the worst case combination of parameters from two ALSEPs. This is based on providing two calibration routines for each experiment, two calibration/limit test routines for each housekeeping subsystem and a separate set of constants for each calibration category.

Sizing Estimates

A. Instructions executed per data word = 40

B. Instructions - one ALSEP = 240 = 960 bytes

C. Instructions - two ALSEPs = 320 = 1,280 bytes*

D. Table storage - one ALSEP = 1,280 bytes

E. Table storage - two ALSEPs = 1,700 bytes*

*It is assumed that the instructions and tables for a number of the routines will be common to both ALSEPs.

7. Display (Figure 8) - At the completion of each experiment and subsystem housekeeping cycle the display function is initiated. Parameters are read out of one of two alternate buffers, assembled in a work area and output to the appropriate display devices. Parameters in the next cycle will be loaded into the other alternate buffer. Thus, one buffer is being loaded while the other one is being read out. In order to keep the work area from becoming too large, only a portion of the parameters in the buffer is assembled for display at one time. After each group of parameters in the work area is output to a display device a program interrupt will occur. The next group of parameters will then be assembled, an output initiated and control will be returned to the interrupted program. The passive seismic experiment parameters are displayed in analog form on drum recorders. Selected magnetometer and cold cathode gauge experiment parameters are displayed on strip chart recorders. The subsystem housekeeping parameters, command verification words, magnetometer parameters, solar wind parameters, suprathermal ion detector parameters and cold cathode gauge parameters are displayed in digital form on high-speed printers. Selected housekeeping parameters and command verification words are presented on display lights.

   Sizing Estimates

   A. Instructions executed per data word = 30

   B. Instructions - one ALSEP = 225 = 900 bytes

   C. Instructions - two ALSEPs = 450 = 1800 bytes

   D. Table storage - one ALSEP = 21,131 bytes

   E. Table storage - two ALSEPs = 42,262 bytes

   F. Work area - one ALSEP = 3,000 bytes

   G. Work area - two ALSEPs = 6,000 bytes

8. Total Program (Figure 1) - The total program consists of the ALSEP processing functions described in 1-7 above and a real-time executive routine which handles all input/output activities. It is estimated that the executive routine would require 4,000 words of

core storage and would impose an overhead on the ALSEP processing functions of up to 50% (i.e., not more than one executive routine instruction would have to be executed for every two ALSEP processing function instructions executed.)* The executive routine 1) answers interrupts and directs control to the proper handling routines; 2) suspends routines during an interrupt cycle and restores them at the earliest opportunity; 3) allows communication between user routines and the executive; and 4) sequences the handling of tasks according to a preset priority structure.

Sizing Estimates

A. Combined ALSEP function for two ALSEPs

1. Instructions executed per data word = 104

2. Instructions = 1,315 = 5,260 bytes

3. Table storage = 59,742

4. Work area = 7,435

B. Executive Routine

1. Instructions executed per data word (50% overhead) = 52

2. Instructions = 4,000 words = 16,000 bytes

C. Total Program

1. Instructions executed per data word = 156

2. Core storage = 88,437 bytes

COMPUTER SYSTEM REQUIREMENTS

The proposed ALSEP program would execute up to 156 instructions per data word processed. Since the combined input rate for two ALSEPs is 212 parameters per second, the ALSEP computer must be capable of executing 33,100 instructions per second. A core storage capacity of 88,437 bytes or approximately 32,000, 24 to 36-bit words would be required

*Computer vendors generally provide a suitable executive routine for each of their real-time computers. For example a 3,500 word executive routine is provided with the Scientific Data System Sigma 7 and a 3,753 word executive system is provided with the Univac 418II.

for instructions, data tables and work areas. An additional 100,000 bytes of disk storage would be required for display format tables. A card reader/punch and magnetic tape unit would be required for routine computer system functions (e.g., loading programs, storing systems software, etc.).

The parameters are to be displayed in analog form on drum and strip chart recorders, and in digital form on high speed printers and display lights.* Eight drum recorders would be used to display the passive seismic experiment parameters. Three eight-channel strip chart recorders would be used to display gauge experiments. Since these experiments represent 11% of the ALSEP parameters, the strip chart recorders must be capable of displaying up to 23 parameters per second.

Selected housekeeping parameters and command verifi

Two high-speed printers would be used to present separate displays for the two ALSEPs. Subsystem housekeeping parameters, command verification words, and selected experiment parameters would be displayed. Since this class of parameters represents 33% of the ALSEP parameters, the printers must be capable of displaying up to 70 parameters per second. Assuming that four parameters with the appropriate headings could be displayed on a printer line, the combined output of the printers would have to be 1,050 lines per minute.** Thus the printers would each have to be capable of printing 525 lines per minute.

A communications network interface terminal would be required to route the ALSEP parameters and commands between the MSFN sites and the flight support computer.

A command console typewriter would be required to initiate commands to the ALSEPs and to request changes in display formats.

In summary, the computer system would consist of the following basic features:

1. A central processing unit capable of executing at least 35,000 instructions per second with a core storage capacity of 90,000 bytes or 32,000 24 to 36-bit words.

2. Two 600 lines-per-minute printers, a card reader/punch unit, a number of display lights, and a command console typewriter attached to a computer input/output channel.

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*Based on requirements stated in References 2 and 3.

**Lines per minute = 70/4 x 60 = 1,050

3. A magnetic tape unit and 100,000 byte disk unit attached to a computer input/output channel.

4. Eight drum recorders and three 8-channel strip chart recorders attached to a computer input/output channel.

5. A communication network interface terminal attached to a computer input/output channel.

CONCLUDING REMARKS

Real time flight support for the ALSEP missions could be performed on a dedicated computer system or on a multi-purpose computer system. The estimates developed in the report can be used to indicate the total requirements for a dedicated system or the ALSEP portion of the requirements for a multi-purpose system.

ACKNOWLEDGEMENT

The author hereby expressed his appreciation for contributions to this memorandum by Mr. W. J. Martin of Department 1031.

Robert J. Pauly

1031-RJP-cak

R. J. Pauly

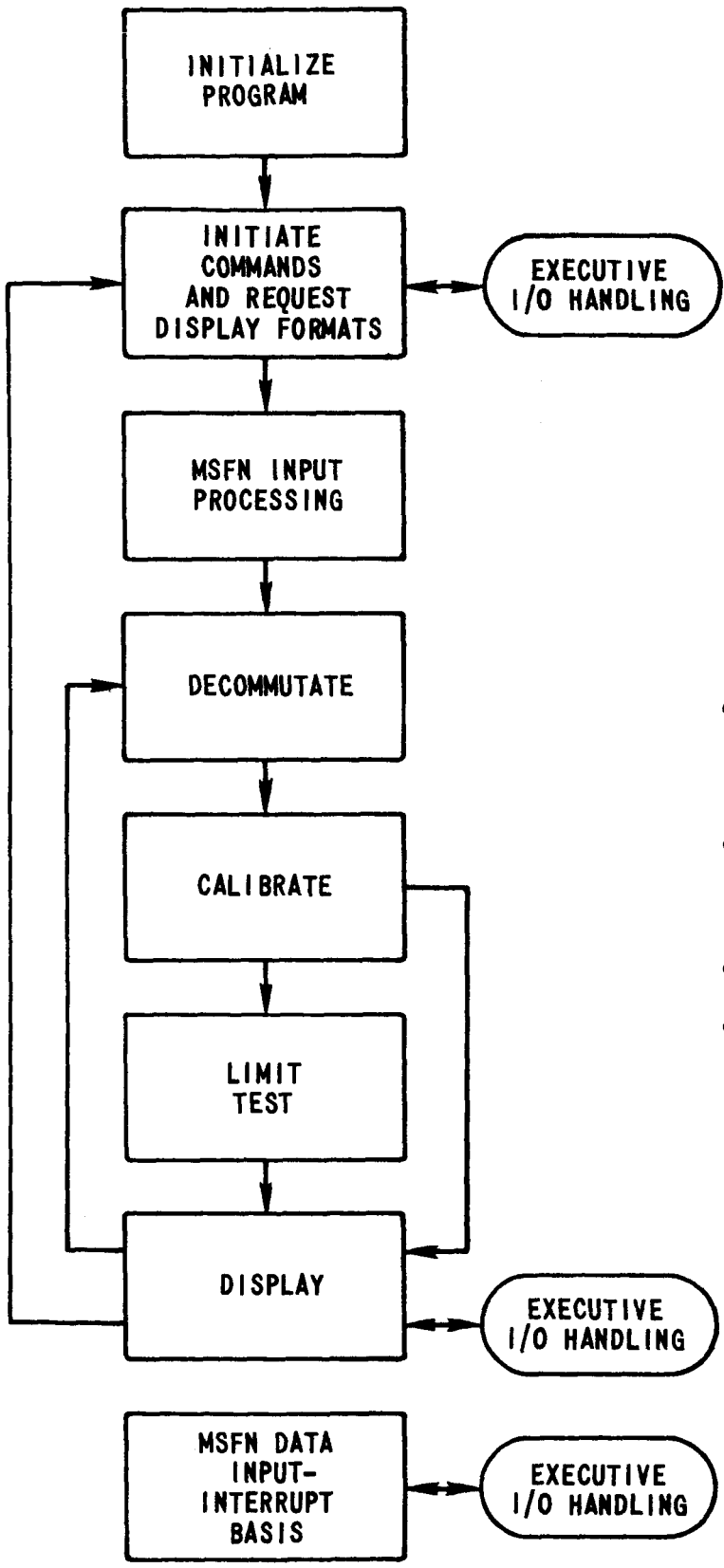
Attachment
References
Figures 1-8

References

1. "System Definition Handbook for Apollo Lunar Surface Experiment Package," October 28, 1966, The Bendix Corporation, Contract NAS9-5829.

2. "Statement of Requirements, SR 502," February 7, 1968, NASA Manned Spacecraft Center, Flight Control Division.

3. "Interface Control Specification for MSFN/MCC-H, December 12, 1967, The Bendix Corporation, Contract NAS9-5829.



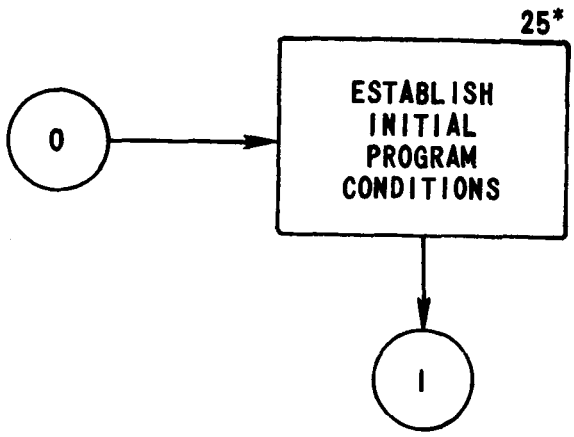
SIZING ESTIMATES

INSTRUCTIONS EXECUTED PER DATA WORD = 104

- TOTAL INSTRUCTIONS (WORDS)
  - ONE ALSEP = 773
  - TWO ALSEPS = 1,315
- TABLE STORAGE (BYTES)
  - ONE ALSEP = 30,301
  - TWO ALSEPS = 59,742
- WORK AREA (BYTES)
  - ONE ALSEP = 4,305
  - TWO ALSEPS = 7,435
- EXECUTIVE (I/O HANDLING)
  - INSTRUCTIONS EXECUTED (50% OVERHEAD) = 52
- INSTRUCTIONS(WORDS)= 4,000
- GRAND TOTAL
  - INSTRUCTIONS EXECUTED PER DATA WORD = 156
  - CORE STORAGE FOR TWO ALSEPS = 88,437 BYTES*

*INSTRUCTION WORDS WERE MULTIPLIED BY FOUR TO CONVERT TO BYTES

FIGURE I - ALSEP PROGRAM

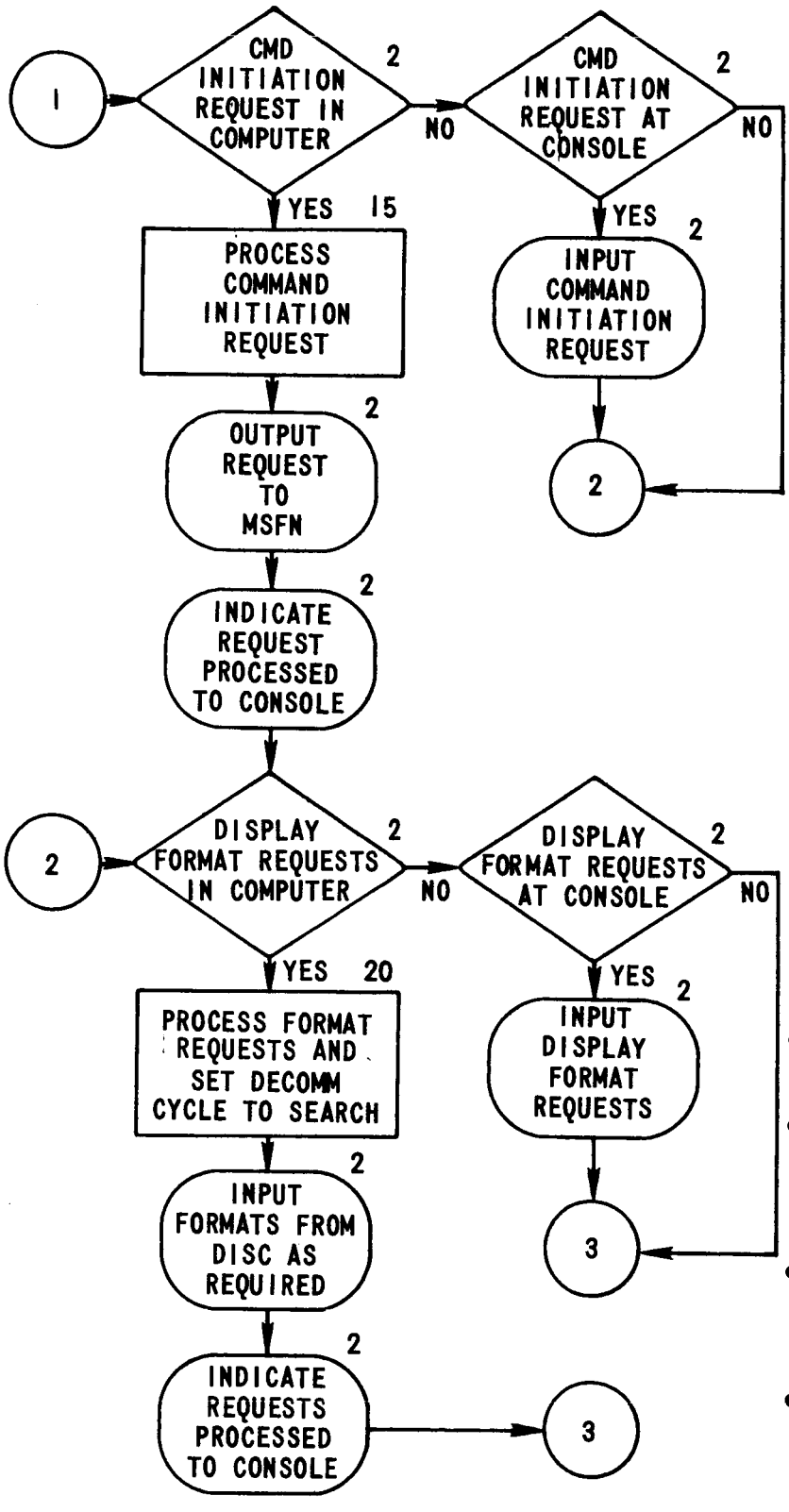


SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD $\simeq 0$
- INSTRUCTIONS (WORDS)
  - ONE ALSEP = 25
  - TWO ALSEPS = 50

*ESTIMATE OF THE NUMBER OF INSTRUCTIONS REQUIRED TO PERFORM THIS ACTIVITY.

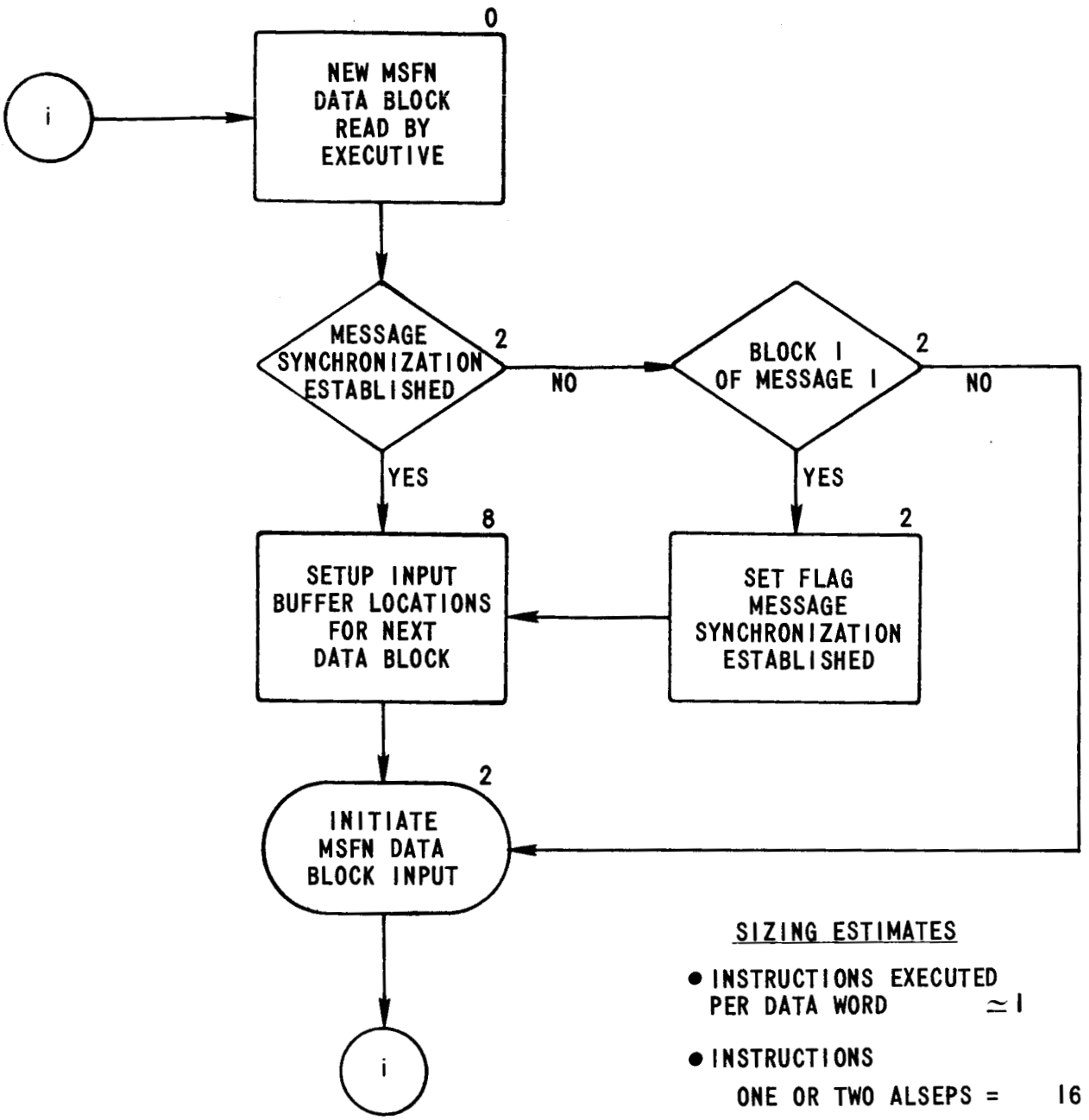
FIGURE 2 - INITIALIZE PROGRAM



SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD = 1
- INSTRUCTIONS (WORDS)
  - ONE ALSEP = 55
  - TWO ALSEPS = 55
- TABLE STORAGE (BYTES)
  - ONE ALSEP = 530
  - TWO ALSEPS = 1,060
- WORK AREA (BYTES)
  - ONE ALSEP = 25
  - TWO ALSEPS = 25

FIGURE 3 - INITIATE COMMANDS AND REQUEST DISPLAY FORMATS

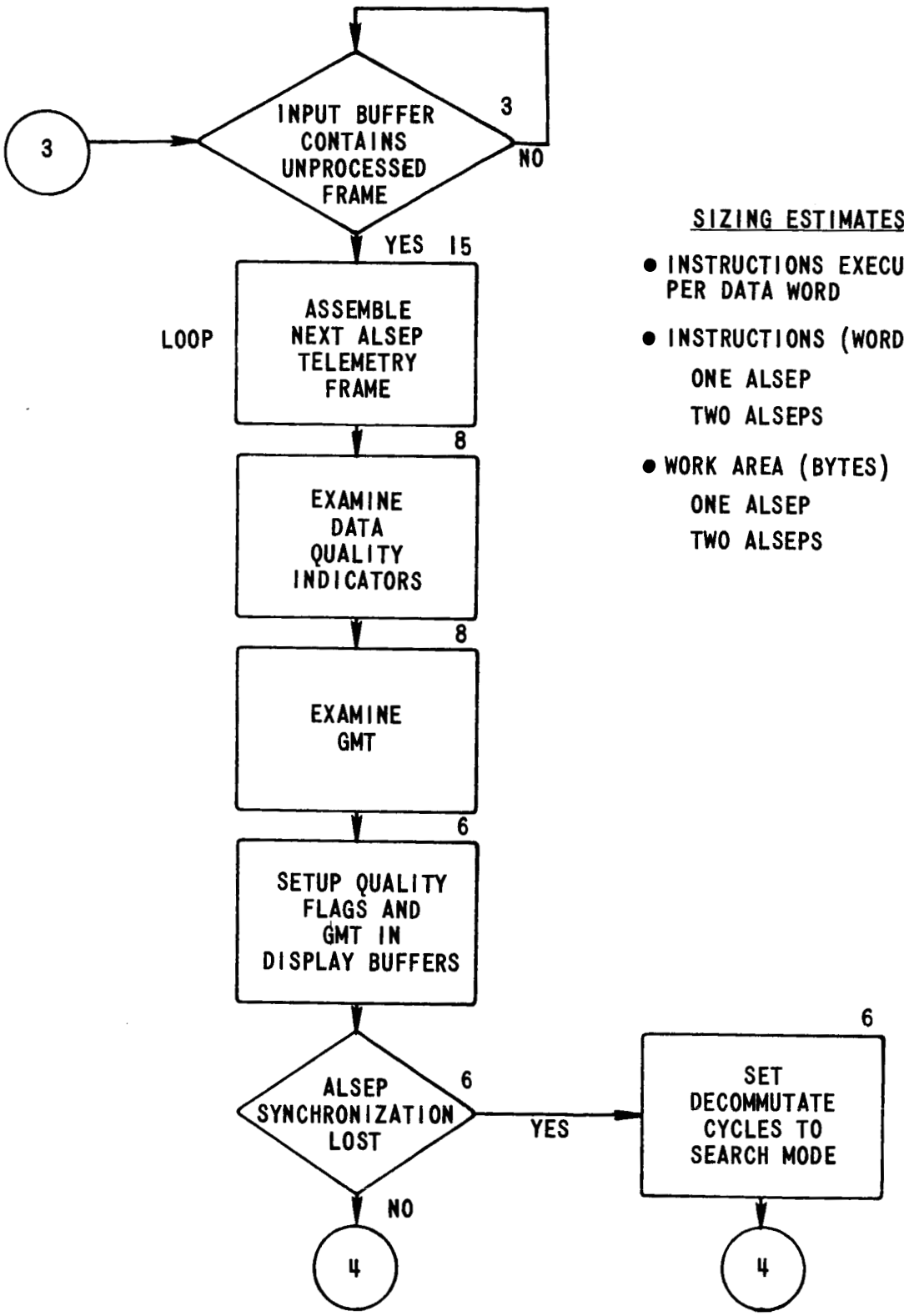


SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD $\simeq 1$
- INSTRUCTIONS
  ONE OR TWO ALSEPS = 16
- WORK AREA (BYTES)
  ONE OR TWO ALSEPS = 1,150

*i - INDICATES AN ENTRANCE OR EXIT FROM THE EXECUTIVE ROUTINE, AS A RESULT OF AN INTERRUPT.

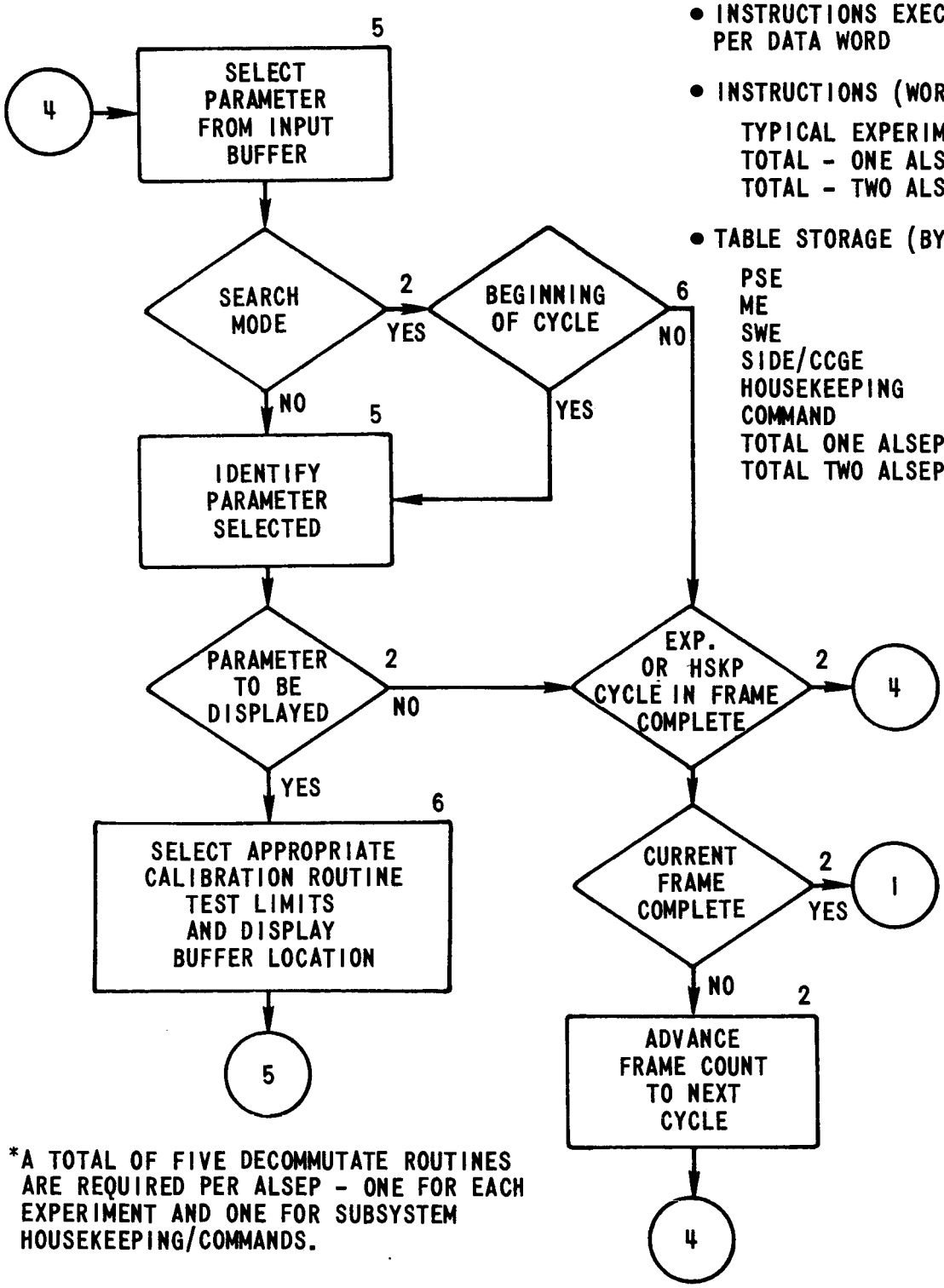
FIGURE 4 - MSFN DATA INPUT



SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD = 12
- INSTRUCTIONS (WORDS)
  - ONE ALSEP = 52
  - TWO ALSEPS = 104
- WORK AREA (BYTES)
  - ONE ALSEP = 130
  - TWO ALSEPS = 260

FIGURE 5 - MSFN INPUT PROCESSING

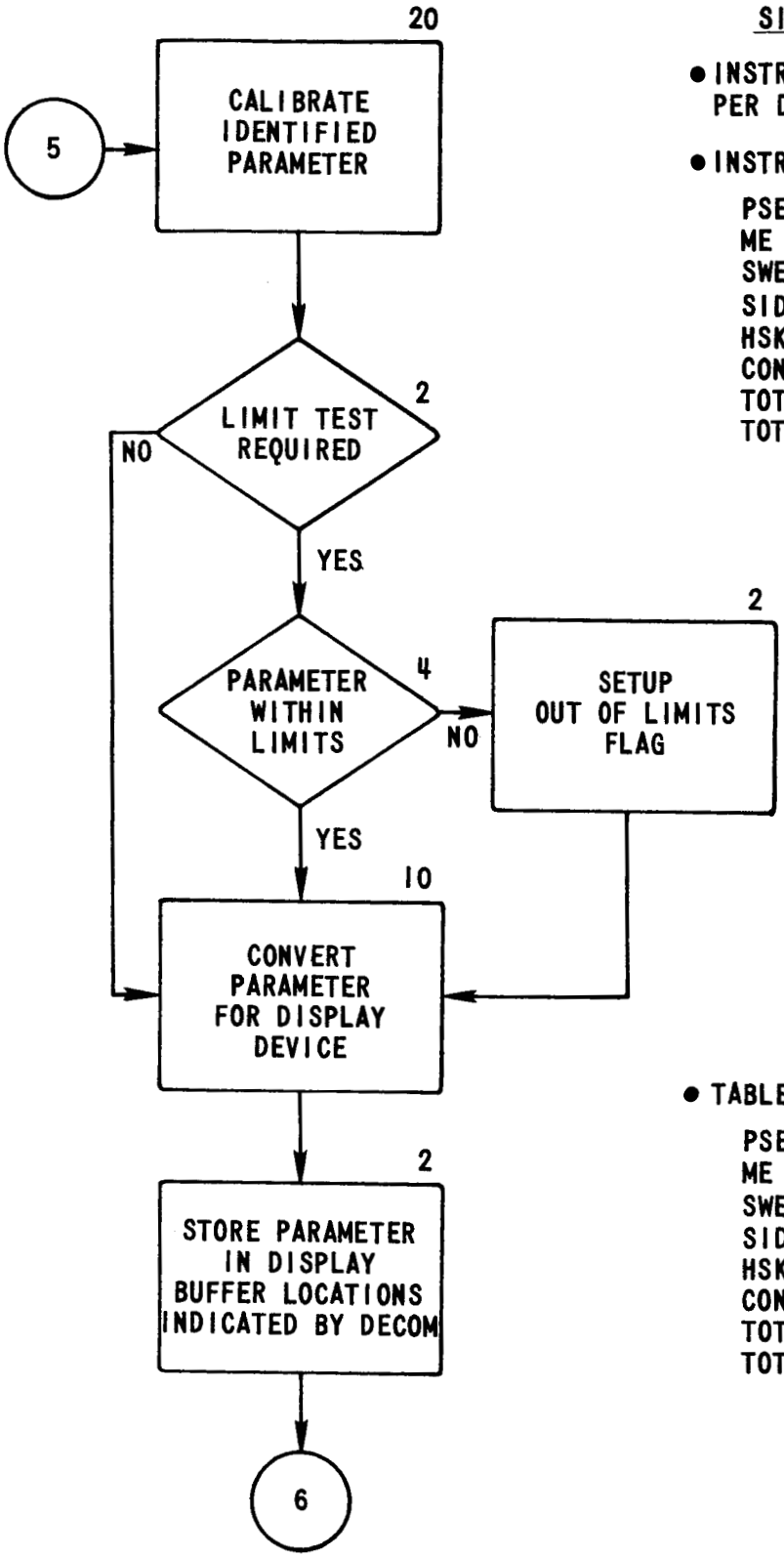


SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD = 20
- INSTRUCTIONS (WORDS)
  - TYPICAL EXPERIMENT = 32*
  - TOTAL - ONE ALSEP = 160
  - TOTAL - TWO ALSEPS = 320
- TABLE STORAGE (BYTES)
  - PSE = 400
  - ME = 450
  - SWE = 650
  - SIDE/CCGE = 5,130
  - HOUSEKEEPING = 720
  - COMMAND = 10
  - TOTAL ONE ALSEP = 7,360
  - TOTAL TWO ALSEPS = 14,720

*A TOTAL OF FIVE DECOMMUTATE ROUTINES ARE REQUIRED PER ALSEP - ONE FOR EACH EXPERIMENT AND ONE FOR SUBSYSTEM HOUSEKEEPING/COMMANDS.

FIGURE 6 - DECOMMUTATE



SIZING ESTIMATES

- INSTRUCTIONS EXECUTED PER DATA WORD = 40

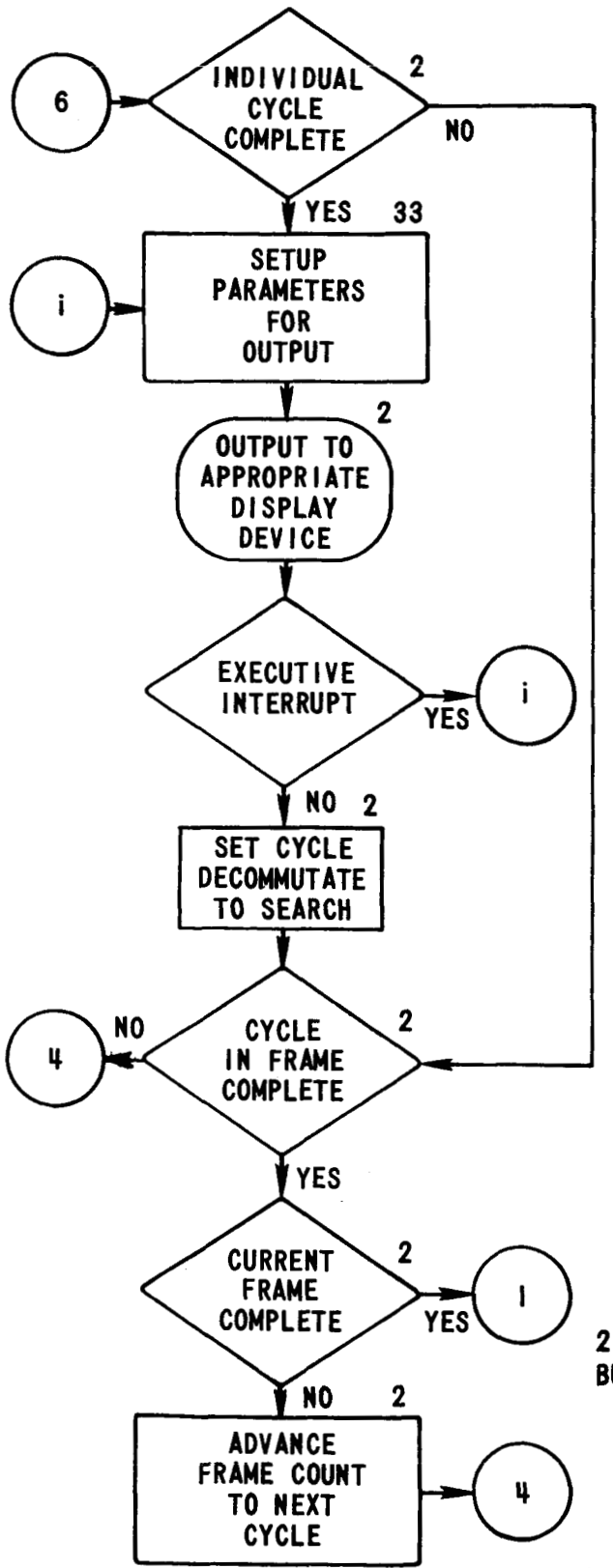
- INSTRUCTIONS (WORDS)

PSE (2 ROUTINES)	=	40
ME (2 ROUTINES)	=	40
SWE (2 ROUTINES)	=	40
SIDE/CCGE (2 ROUTINES)	=	40
HSKP (2 ROUTINES)	=	50
CONVERT (3 ROUTINES)	=	30
TOTAL ONE ALSEP	=	240
TOTAL TWO ALSEPS	=	320

- TABLE STORAGE (BYTES)

PSE (5 TYPES)	=	50
ME (5 TYPES)	=	50
SWE (12 TYPES)	=	120
SIDE/CCGE (30 TYPES)	=	300
HSKP (46 TYPES)	=	460
CONVERT (3 TYPES)	=	300
TOTAL ONE ALSEP	=	1,280
TOTAL TWO ALSEPS	=	1,700

FIGURE 7 -CALIBRATE AND LIMIT TEST



SIZING ESTIMATE

- INSTRUCTIONS EXECUTED PER DATA WORD = 30
- INSTRUCTIONS (WORDS)
  - TYPICAL EXPERIMENT = 45*
  - TOTAL - ONE ALSEP = 225
  - TOTAL - TWO ALSEPS = 550
- TABLE STORAGE (BYTES)
  - ME (2x112x2+30x5)** = 598
  - SWE (2x2976x2+260x5) = 13,204
  - SIDE/CCGE (2x1280x2+196x5) = 6,100
  - PSE (2x86x2+8x5) = 344
  - HSKP (2x90x2+90x5) = 810
  - CMD (2x1x2+1x5) = 9
  - QUALITY/GMT (2x14x2+2x5) = 66
  - TOTAL - ONE ALSEP = 21,131
  - TOTAL - TWO ALSEP = 42,262
- WORK AREA (BYTES)
  - ONE ALSEP = 3,000
  - TWO ALSEPS = 6,000

*A TOTAL OF FIVE DISPLAY ROUTINES ARE REQUIRED - ONE FOR EACH ROUTINE AND ONE FOR SUBSYSTEM HOUSEKEEPING/ COMMANDS.

30 PARAMETER HEADINGS — 5 BYTES PER HEADING

**ME (2 x 112 x 2 + 30 x 5)

2 DISPLAY BUFFERS — 112 SAMPLES IN EACH DISPLAY CYCLE — 2 BYTES PER SAMPLE

FIGURE 8 - DISPLAY